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Bioresource Technology 99 (2008) 1538–1543

BIORESOURCE TECHNOLOGY

The effects of heat treatment on technological properties in Red-bud maple (*Acer trautvetteri* Medw.) wood

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Received 28 February 2007; received in revised form 11 April 2007; accepted 12 April 2007
Available online 4 June 2007

Abstract

Heat treatment is often used to improve the dimensional stability of wood. In this study, the effects of heat treatment on technological properties of Red-bud maple (*Acer trautvetteri* Medw.) wood were examined. Samples obtained from Düzce Forest Enterprises, Turkey, were subjected to heat treatment at varying temperatures (120 °C, 150 °C and 180 °C) and for varying durations (2 h, 6 h and 10 h). The technological properties of heat-treated wood samples and control samples were tested. Compression strength parallel to grain, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength, and tension strength perpendicular to grain were determined.

The results showed that technological strength values decreased with increasing treatment temperature and treatment times. Red-bud maple wood could be utilized by using proper heat treatment techniques with minimal losses in strength values in areas where working, and stability such as in window frames, are important factors.

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Keywords: Red-bud maple; *Acer trautvetteri* Medw.; Technological properties; Heat treatment

1. Introduction

There are nine maple species and 19 maple taxons native to Turkey. Tatarian maple (*Acer tataricum* L.), Red-bud maple (*A. trautvetteri* Medw.), Norway maple (*A. platonoides* L.), Montpelier maple (*A. monspessulanum* L.), Cretan maple (*A. sempervirens*), Balkan maple (*A. hyrcanum* Fret. M.), Hedge maple (*A. campestre* L.), Cappadocium maple (*A. cappodocicum* Gledt) and Divergent maple (*A. divergens* Pax) are the most important species grown in Turkey (Yaltırık, 1968).

In the 1980s, maple woods produced from Turkish forests exceeded 10,000 m^3 yearly (Carus, 1992). However, since then, maple lands have been gradually decreased and today they cover about 3000 ha land area and with less than 1000 m^3 total standing wood volume (Anonymous, 2001). Red-bud maple is a species only found in the Anatolian and Caucasus regions of the world. It grows rapidly at a range of altitudes and climatic conditions.

Maple has a variety of uses, for example; tourist giftware, carpentry tools, furniture, panels, parquet, lumber, LVL (Laminated Veneer Lumber), glulam, musical instruments, tool handles, rifle butts, decoration material, horizontal beam, shoe-making, aircraft propellers, wooden bridges, to name a few (Yaltırık, 1970).

Many studies have been conducted in order to improve the properties of wood. The methods devised, based on the results of these studies, are commonly named "Wood Modification Methods". Heat treatment, as a wood modification method, serves to improve the natural qualities and properties of the wood such as dimensional stability, permeability and resistance to bio-corrosion and equip the

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0960-8524/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2007.04.021

wood material with new properties. Heat treatment is also expected to decrease equilibrium moisture content (Mazela et al., 2004).

Industrial-scale heat treatment process of wood was developed at the Technical Research Centre of Finland in the early 1990s. The total production capacity of heat-treated wood in 2002 is estimated approximately to be 265,000 m^3. Recent efforts on thermal treatment of wood have led to the development of several treatment processes and materials produced through thermal treatments have been introduced to the European market. This has resulted in the development of Thermowood (Stellac) in Finland (Viitaniemi et al., 1994), Torrefaction (Perdure) in France (Weiland and Guyonnet, 1997) and PLATO®-wood in the Netherlands (Syrjanen and Oy, 2001).

The temperature and duration for heat treatment generally vary from 180 to 280 °C and 15 min to 24 h depending on the heat treatment process, wood species, sample size, moisture content of the sample, and the desired mechanical properties, resistance to biological attack, and dimensional stability of the final product (Kamdem et al., 2002; Militz, 2002). Temperature has a greater influence than time on many properties. Treatment at lower temperatures for longer periods, however, does not give similar results compared to treatments at higher temperatures. Temperatures over 150 °C alter the physical and chemical properties of wood permanently. At the same time, strength properties start to weaken (Mitchell, 1988). The higher the treatment temperature, the better the wood's biological durability. However, the wood's mechanical properties are made weaker. The wood becomes more brittle, bending and tension strengths decrease by 10–30%. Therefore, the use of heat-treated wood in load-bearing constructions is restricted (Jämsä and Viitaniemi, 2001).

In a study on Spruce (*Picea abies*) wood, heat treatment for 24 h resulted in a weight loss of 0.8% and 15.5% at 120 °C and 200 °C, respectively (Fengel, 1966).

On the other hand, hardness and strength of wood decrease when heated and increase when cooled. These effects are achieved with heat treatment applied for a long time. With heat treatment, the least affected property is modulus of elasticity while the most affected strengths are impact and static bending strengths (MacLean, 1954).

Heat-treated wood has been considered as an ecological alternative to impregnated wood materials, and it can be used for several purposes, e.g. for garden, kitchen and sauna furniture, floors, ceilings, inner and outer bricks, doors and windows (Rapp et al., 2001). To our knowledge, there is no information about the influence of heat treatment on some technological properties, such as compression strength, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain of Red-bud maple wood.

The main aim of this study is to understand the effect of heat treatment on Red-bud maple woods' characteristics, so enabling this wood to be used more widely and effectively by the timber products industry.

2. Methods

Five trees with a diameter at breast height diameter (DBH 1.3 m above ground) of 35–40 cm were obtained from Düzce Forest Enterprises. The area from which the trees were taken was at an elevation of 1306 m and had a slope of 61% (TS 4176, 1984). Lumber from the logs was prepared by AKE Sawmill Ltd. Red-bud maple lumber was finished by a fixed-knife planer with a feed speed of 1 m/s. Red-bud maple lumber was planed with a knife angle of 45° and then small clear specimens were cut for: compression strength parallel to grain (2 × 2 × 3 cm), bending strength (2 × 2 × 36 cm), modulus of elasticity in bending (2 × 2 × 36 cm), janka-hardness (5 × 5 × 5 cm), impact bending strength (2 × 2 × 30 cm) and tension strength perpendicular to grain (2 × 3 × 7 cm) (TS 2470, 1976a). The wood pieces were sawn with the annual rings at a 45° angle to the surface so that the deformations would be smaller, the hardness of the surface would be stronger and the "general look" after heat treatment was better.

The number of specimens taken from each log was equal. Heat treatment applications were applied at three temperatures (120–150–180 °C) and three durations (2–6–10 h) in a small heating unit controlled at ±1 °C sensitivity under atmospheric pressure. After heat treatment, treated and untreated samples were conditioned to 12% moisture contents (MC) in a conditioning room at 20 ± 2 °C and 65% (±5) relative humidity (RH) (TS 642 ISO 554, 1997). Prior to the test, the dimensions were measured to the nearest 0.001 mm and their weights were recorded to the nearest 0.01 g.

Compression strength parallel to grain (TS 2595, 1976g), bending strength (TS 2479, 1982), modulus of elasticity in bending (TS 2476, 1976d), janka-hardness (TS 2477, 1976e), impact bending strength (TS 2478, 1976f) and tension strength perpendicular to grain (TS 2474, 1976c) measurements were carried out for treated and untreated samples, based on Turkish Standards (TS).

After strength tests, the moisture content of samples was measured. Strength values were adjusted for the wood samples with moisture content greater or lower than 12% (TS 2471, 1976b).

For all parameters, all multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between mean values of control and treated samples were determined using Duncan's Multiple Range Test. P-values of $\leqslant 0.05$ were considered significant.

3. Results and discussion

Table 1 shows the results of compression strength parallel to grain, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength, and tension strength perpendicular to grain, for the control and all the different heat treatment and time combinations. According to the averages, all the parameters decreased

Table 1
The effect of heat treatment for different durations on technological properties in Red-bud maple (*Acer trautvetteri* Medw.) wood

Heat treatment (°C)	Times (h)	Unit	Compression strength (N/mm^2)	Bending strength (N/mm^2)	Modulus of elasticity in bending (N/mm^2)	Janka-hardness			Impact bending strength (J/cm^2)	Tension strength perpendicular to grain (N/mm^2)
						Cross-section (N/mm^2)	Radial (N/mm^2)	Tangential (N/mm^2)		
None (Control)		Avg. ± s	75.187 A	135.52 A	12216.621 A	97.361 A	63.395 A	70.814 A	6.173 A	3.989 A
			7.339	13.936	1574.915	7.247	7.509	6.335	2.029	0.875
120	2	Avg. ± s	73.664 A	132.733 ACDEF	12131.17 ABCDEFGH	74.796 BCDEFGHIK	34.46 BEFGHIK	40.02 BIK	6.112 ABC	3.814 ACDEF
			15.676	23.1480	2000.892	4.366	3.087	4.073	1.673	0.855
	6	Avg. ± s	72.158 A	132.076 ACDEF	12102.995 ABCDEFGH	71.656 CHIK	33.86 CIK	38.203 CK	5.937 ABC	3.737 ACDEF
			8.326	22.876	1842.344	3.441	9.231	6.931	1.419	0.668
	10	Avg. ± s	71.950 A	130.764 ACDEF	11122.798 BGH	71.406 DHIK	33.53 DIK	38.1566 DK	5.646 ABC	3.551 ADEF
			15.128	4.273	842.572	4.487	3.672	2.656	1.907	1.118
150	2	Avg. ± s	70.388 A	126.65 ADEF	10718.351 CH	71.253 EHIK	31.666 E	37.963 EK	5.618 ABC	3.548 ACDEF
			12.071	25.511	1627.886	6.585	5.092	3.726	1.624	0.890
	6	Avg. ± s	70.119 A	123.3533 BDEF	10451.063 DH	70.31 FK	31.43 F	37.62 FK	5.576 ABC	3.332 BDEF
			10.626	20.605	1819.030	3.138	1.827	4.852	1.876	1.175
	10	Avg. ± s	69.244 A	117.422 CEF	10277.738 EH	70.043 GK	31.356 G	37.61 GK	5.342 ABC	3.064 CEF
			8.259	16.270	1645.929	3.781	3.763	3.399	0.767	1.090
180	2	Avg. ± s	69.116 A	109.873 DF	10232.384 FH	68.526 H	31.15 H	37.56 HK	5.300 ABC	2.721 DEF
			13.138	15.325	2255.629	3.891	2.277	3.574	1.793	0.684
	6	Avg. ± s	68.546 BC	106.553 EF	9866.894 GH	68.476 I	30.093I	36.5 IK	4.075 B	2.171 E
			6.852	24.768	2246.601	5.390	3.050	3.189	1.2569	0.694
	10	Avg. ± s	50.904 C	92.423 F	8755.584 H	66.93 K	29.053K	34.57 K	3.520 C	2.131 F
			1.175	21.639	1377.224	4.199	3.136	4.934	0.924	0.600

Avg. = average; ± s = standard deviation; number of samples (30) used in each test.

Homogeneity groups: same letters in each columns indicate that there is no statistical difference between the samples according to the Duncan's multiply range test at $P < 0.05$. Comparisons were between each control and its test.

Table 2
Percentage decrease of technological properties in Red-bud maple (*Acer trautvetteri* Medw.) wood following heat treatment for different durations

Heat treatment (°C)	Times	Compression strength (%)	Bending strength (%)	Modulus of elasticity in bending (%)	Janka-hardness			Impact bending strength (%)	Tension strength perpendicular to grain (%)
					Cross-section	Radial	Tangential		
120	2	2.026	2.056	0.669	23.176	45.642	43.486	0.989	4.373
	6	4.029	2.540	0.930	26.401	46.589	46.051	3.825	6.309
	10	4.305	3.509	8.953	26.658	47.109	46.117	8.532	10.974
150	2	6.383	6.545	12.264	26.816	50.049	46.390	8.991	11.053
	6	6.740	8.977	14.452	27.784	50.422	46.875	9.662	16.473
	10	7.905	13.354	15.870	28.058	50.538	46.889	13.464	23.183
180	2	8.074	18.924	16.242	29.616	50.864	46.959	14.134	31.771
	6	8.832	21.374	19.233	29.667	52.530	48.456	33.989	45.576
	10	32.297	31.800	28.330	31.256	54.171	51.182	42.972	46.563

with increasing temperature and time. The effect of the heat treatments was significant for all the variables analyzed.

It is clear from this study that the value of all measured technological properties decreased with increasing temperature and duration. Table 2 shows the percentage decrease of values in relation to the control for each treatment and each measured parameter.

The maximum decreases for all parameters were recorded at the treatment of 180 °C for 10 h. The lowest compression strength values obtained was 50.904 N/mm^2, total loss compared to the control was calculated to be 32.297%. Similarly, the lowest bending strength values were also obtained for samples treated at 180 °C for 10 h (92.423 N/mm^2). The bending strength loss, compared to the control was 31.8%. The lowest modulus of elasticity in bending values was again obtained for samples treated at 180 °C for 10 h (8755.584 N/mm^2). The decrease in modulus of elasticity in bending was 28.330%. The lowest impact bending strength values was for samples treated at 180 °C for 10 h (3.520 J/cm^2). The loss of impact bending strength when compared to controls, was 42.972%. The lowest tensile strengths perpendicular to grain values were at 180 °C for 10 h (2.131 N/mm^2). The loss of tensile strength perpendicular to grain was 46.563%. Maximum hardness loss was obtained for samples treated at 180 °C for 10 h; cross-section 31.256%, radial 54.171% and tangential 51.182%.

The parameters measured varied in their rate of decrease, some experiencing a gradual loss, others exhibiting more dramatic changes (Fig. 1). The janka-hardness values are greatly affected by initial treatments but after that only show a gradual decrease with increasing temperatures and treatment times. In contrast the strength values do not start to show significant changes with the lower temperature treatment of 120 °C but an increase in temperature starts to have an effect. The most stable is compression strength not showing a great decrease until the maximum treatment of 180 °C for 10 h. Similar results were also reported previously (Yildiz et al., 2006). Vital et al. reported a study of compression parallel to grain in *Eucalyptus saligna* wood samples heated to 100–155 °C for 10–160 h, and they found that the compression strength values generally deteriorated with increase in temperature or exposure time (Vital et al., 1983).

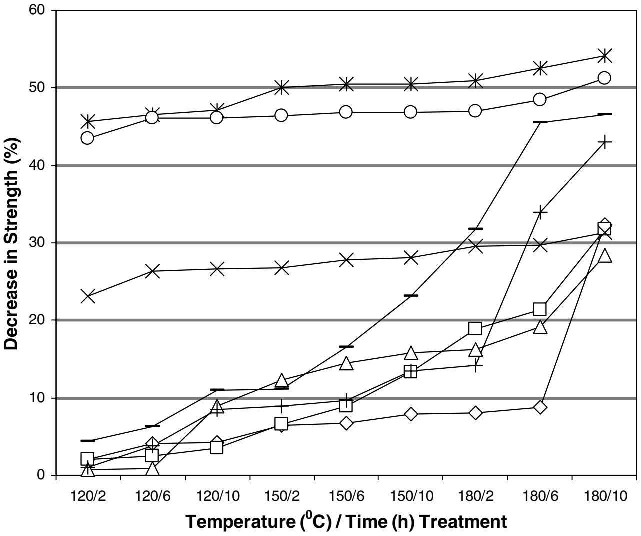

Fig. 1. Percentage decrease of technological properties in Red-bud maple (*Acer trautvetteri* Medw.) wood following heat treatment for different durations. (♦) compression strength; (□) bending strength; (△) modulus of elasticity in bending; (×) Janka-hardness cross-section; (∗) Janka-hardness radial; (○) Janka-hardness tangential; (+) impact bending strength; (—) tension strength perpendicular to grain.

A study on both spruce (*Picea orientalis* L.) and beech (*Fagus orientalis* L.) heated at 200 °C for 6 h resulted in a 36% decrease in compression strength. On the other hand, a slight increase in compression strength was observed at 130 °C for 6 h. In the same study, it was emphasized that compression strength was affected less by temperature increase compared to other strength properties. The highest decrease in modulus of elasticity for spruce was found to be 41.5% at 200 °C for 6 h. On the other hand, a slight increase (8.4%) in modulus of elasticity was observed at 130 °C for 10 h treated samples. For beech, heat treatment at 200 °C for 10 h resulted in an increase in modulus of elasticity (39%). The lowest bending strengths for beech and spruce were observed when the wood samples were treated at 200 °C for 6 h and 10 h. The decrease was 63.9% and 63.6% for beech and 63.8% and 72.7% for spruce at 6 h and 10 h respectively. The greatest decrease in hardness values was observed when beech and spruce samples were treated at 180 °C for 10 h. For beech samples, 25.9%, 45.1%, and 41.8% decrease in hardness was observed for cross-section, radial direction and tangential direction, respectively. For spruce 19.7%, 43.0% and 42.5% decrease was observed for cross-section, radial direction and tangential direction, respectively (Yildiz, 2002).

In general the results of this study on the effect of heat treatment on Red-bud maple are compatible with the findings in literature on the effect of heat treatment on different tree species. Ünsal et al. (2003) reported that in Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) wood samples the largest hardness loss was at 180 °C for 10 h treatment. The loss was 23.91% cross-sectionally, 44.20% radially, and 33.57% tangentially. Unsal and Ayrilmis (2005) also found that the maximum compression strength parallel to grain decrease in Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) wood samples was 19.0% at 180 °C for 10 h treatment. Korkut (in press) obtained similar compression strength results for Uludağ fir (*Abies bornmuellerinana* Mattf.) wood for the same treatment time and temperature. In this case it can be said that temperature has greater influence on strength properties than time.

Yildiz (2002) found that the elasticity modulus and compression strength values of the same wood samples decreased by thermal modification, however, water repellence efficiency of the same wood samples (spruce and beech) increased when heated at the same temperature and duration.

In a study on the effect of heat treatment, with pine sapwood heated at 110, 130, 150 and 180 °C it was found that compression strength decreased by 5% (Schnerder, 1973). Similarly another study showed that for Eucalyptus (*E. saligna*) wood, compression strength parallel to grain decreased at 110–155 °C for 10–160 h treatments (Vital et al., 1983).

The decreases in the strength properties can be explained by the rate of thermal degradation and losses of substance after heat treatments. The decrease in strength is mainly due to the depolymerization reactions of wood polymers (Kotilainen et al., 2000). The primary reason for the strength loss is the degradation of hemicelluloses, which are less resistant to heat than cellulose and lignin. Changes in or loss of hemicelluloses play key roles in the strength properties of wood heated at high temperatures (Hillis, 1984).

4. Conclusion

The smallest decrease was determined at the heat treatment of 120 °C for 2 h. In this research, technological strength values all decreased with increasing time and temperature treatments. The largest decrease found was for radial hardness, followed by tangential hardness and the tension strength perpendicular to grain, when heat treated at 180 °C for 10 h under the conditions stated.

The improved characteristics in swelling and surface roughness of heat-treated timber have to be balanced against the decrease in strength values when evaluating the effectiveness of using this treatment. Strength losses can be limited through alternative modified heat treatment techniques. Various tree species can be utilized using proper heat treatment techniques without any loses in strength values in areas where woodworking and stability are important. Wood species having no commercial value can also be utilized effectively, following heat treatment, in areas where they previously had little potential.

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